

INVESTIGATION OF PRESSURE
AND TEMPERATURE CHANGES
AT THE BASE OF THE STRATOSPHERE

Paul R. Drouilhet
and
Ross R. Kellerman

INVESTIGATION OF PRESSURE AND TEMPERATURE CHANGES AT THE

BASE OF THE STRATOSPHERE

by

Paul R. Drouilhet
U.S. Naval Academy

1927

and

Ross R. Kellerman
U.S. Naval Academy

1927

Submitted in Partial Fulfillment of the Requirements
for the Degree of
MASTER OF SCIENCE
from the

Massachusetts Institute of Technology,

1937

Signature of Authors _____

Department of Meteorology, May 18, 1937

Signature of Professor
in Charge of Research _____

Signature of Chairman of Department Committee
on Graduate Students _____

INVESTIGATION OF THEORETICAL AND EXPERIMENTAL DESIGN AT THE

BASE ON THE STATISTICS

by

Paul A. Huxford

U.S. Naval Academy

no.
096

1937

and

Norman A. Huxford

U.S. Naval Academy

1937

Submitted in partial fulfillment of the requirements

for the degree of

MAJOR IN SCIENCE

from the

Naval Academy Institute of Technology.

1937

Signature of Author

Department of Technology, May 10, 1937

Signature of Professor
in Charge of Research

Signature of Chairman of Research Committee
on Graduate Studies

TABLE OF CONTENTS

	Page
I. Introduction	1-2
II. Resume of Investigations by W.H.Dines, F.R.S.	3-5
III. Resume of Investigations by E. Palmen	6-13
IV. Analysis of Conditions over Stations in the United States	14-30
V. Summary	31-34
VI. Bibliography	35-36

TABLE OF CONTENTS

I.	Introduction	1-2
II.	Summary of Investigation by H. H. Brown, W. H. Brown, & H. H. Brown	2-2
III.	Summary of Investigation by H. H. Brown	2-12
IV.	Analysis of Conditions over Stations in the United States	14-30
V.	Summary	31-34
VI.	Bibliography	35-36

INVESTIGATION OF PRESSURE AND TEMPERATURE CHANGES AT THE

BASE OF THE STRATOSPHERE

I. Introduction

The object of this study is to investigate the pressure and temperature changes in the region of the Tropopause over stations in the United States and to attempt to seek relationships which might clarify or explain the reason for those phenomena that we know to exist in the upper Troposphere. We are particularly interested in those phenomena which give a variation of Tropopause height with a corresponding change of pressure at the nine kilometer level, and the temperature-height curves associated with such changes of atmospheric conditions.

Inasmuch as this investigation parallels closely those of W.H.Dines, Meteorologist in charge of Investigation of the Upper Air for the London Meteorological Office, and E. Palmén, Professor of the Meteorological Institute of the University of Helsingfors, in relation to the subject matter at hand, a brief resume will be given in order to explain the methods used and the results obtained by these two eminent meteorologists.

INVESTIGATION ON PRESSURE AND TEMPERATURE CHANGES AT THE

BASE OF THE STRATOSPHERE

1. Introduction

The object of this study is to investigate the pressure and temperature changes in the region of the troposphere near stratosphere in the United States. It is difficult to establish relationships which might directly or explain the reason for those phenomena that we have to exist in the upper troposphere. We are particularly interested in those phenomena which give a variation of troposphere height with a corresponding change of pressure at the same altitude level, and the temperature-height curves associated with such changes of atmospheric conditions.

Research on this investigation remains almost those of A. S. Jones, developed in terms of investigation of the upper air for the London Meteorological Office, and J. F. Johnson, Government of the Meteorological Institute of the University of Helsinki, in relation to the subject matter at hand, a brief review will be given in order to explain the methods used and the results obtained by these two authors respectively.

Especial thanks are due Professor C.G. Rossby
of the Massachusetts Institute of Technology for his
helpful advice in the preparation of this paper.

of the Government Institute of Technology for the
Technical School in the preparation of this paper.

II. Investigations and Results of W.H.Dines.

The material upon which Dines based his investigations and conclusions consisted of upper air soundings over the British Isles and the Continent of Europe. He took departures from the mean of his sets of soundings and computed total and partial correlation coefficients and regression coefficients between sundry variables of the upper air. His variables were:

1. Pressure in millimeters at sea level.
2. Mean temperature of air column from the 1 to the 9 kilometer level.
3. The pressure at the 9 kilometer level.
4. The height of the Tropopause.
5. The temperature at the Tropopause.

He defined the Tropopause height as that point where the decrease of temperature becomes 1 degree Centigrade or less per kilometer. The formula for obtaining his correlation coefficient was

$$r_{a,b} = \frac{\sum (\delta_a \delta_b)}{n \sigma_a \sigma_b}$$

where

$$\sigma_a = \frac{\sqrt{\sum (\delta_a)^2}}{n} \quad \text{and "a" and "b" represent the}$$

variables being correlated, " " the standard deviation, and "n" the number of ascents.

Dines has listed five sets of correlation coefficients obtained from a similar number of groups and

II. Investigation and Results of A. H. Jones

The material upon which these results are based is the investigation and correlation of the variation of the air velocity over the British Isles and the continent of Europe. The work comprises from the year of 1894 to 1904 and is divided into two parts: the first part is devoted to the investigation of the variation of the air velocity over the British Isles and the continent of Europe, and the second part is devoted to the investigation of the variation of the air velocity over the British Isles and the continent of Europe.

1. The variation of the air velocity over the British Isles and the continent of Europe. The results are given in the following table:

Year	1894	1895	1896	1897	1898	1899	1900	1901	1902	1903	1904
Mean	1.5	1.6	1.7	1.8	1.9	2.0	2.1	2.2	2.3	2.4	2.5

2. The variation of the air velocity over the British Isles and the continent of Europe. The results are given in the following table:

Year	1894	1895	1896	1897	1898	1899	1900	1901	1902	1903	1904
Mean	1.5	1.6	1.7	1.8	1.9	2.0	2.1	2.2	2.3	2.4	2.5

$$\frac{1}{n} \sum_{i=1}^n \frac{1}{D_i} = \frac{1}{D}$$

$$\frac{1}{n} \sum_{i=1}^n \frac{1}{D_i^2} = \frac{1}{D^2}$$

and "n" the number of observations, "D" the mean deviation, and "D²" the mean of squares.

These are the results of the investigation.

These are the results of the investigation.

the British Isles. The correlation coefficients were obtained for all groupings by taking departures from the mean. The mean of the correlation coefficients for the entire five groups were computed and are as follows:

Surface pressure versus mean temperature	0.46
" " " pressure 9 km. level	0.66
" " " Tropopause height	0.69
" " " " temp.	-0.59
Mean temp. versus Pressure 9 km. level	0.92
" " " Tropopause height	0.78
" " " " temp.	-0.39
Press. 9 km. level versus Tropopause height	0.83
" " " " " temp.	-0.49
Tropopause height vs. Tropopause temperature	-0.65

We computed the standard deviations for his various sets of soundings and arrived at the following values for the mean of these standard deviations:

Surface pressure	9.4
Mean temperature	7.0
Pressure at the 9 km. level	9.2
Tropopause height	14.8
Tropopause Temperature	6.6

The units for these values are degrees Centigrade for the temperature, millimeters of mercury for the pressures,

the British Isles. The continental socialists were
determined for all purposes by taking Germany as
the main. The main of the continental socialists
for the entire live force were Germany and the

Station	Depth	Temperature	Salinity	Density	Direction	Speed
0.00	Surf	20.0	35.0	1.020	000	0.0
0.05	5 m	18.5	35.0	1.020	000	0.0
0.10	10 m	17.0	35.0	1.020	000	0.0
0.15	15 m	15.5	35.0	1.020	000	0.0
0.20	20 m	14.0	35.0	1.020	000	0.0
0.25	25 m	12.5	35.0	1.020	000	0.0
0.30	30 m	11.0	35.0	1.020	000	0.0
0.35	35 m	9.5	35.0	1.020	000	0.0
0.40	40 m	8.0	35.0	1.020	000	0.0
0.45	45 m	6.5	35.0	1.020	000	0.0
0.50	50 m	5.0	35.0	1.020	000	0.0

RECEIVED
JAN 10 1964
U.S. DEPARTMENT OF JUSTICE
FEDERAL BUREAU OF INVESTIGATION
WASHINGTON, D.C. 20535

For the purpose of illustration of current law and procedure, the author has selected the following cases:

and 100 meters for the tropopause height.

On the basis of the values of the correlation coefficients coupled with results obtained from partial correlation and regression coefficients, Dines arrived at the following conclusions:

1. The pressure at the 9 kilometer level has a positive effect on the surface pressure and the mean temperature. It is very closely and positively correlated with tropopause height, but he is not certain whether it is as cause or effect. It has a negative effect upon Tropopause temperature.

2. The temperature of the air column from 1 to 9 kilometers has a negative effect upon surface pressure, a large positive effect upon the pressure at the 9 kilometer level, no direct effect upon Tropopause height and a moderate positive effect upon Tropopause temperature.

3. Tropopause height has a positive effect upon surface pressure, no direct effect upon the mean temperature, it is closely correlated with the pressure at the 9 kilometer level, and has a very distinct negative effect upon Tropopause temperature.

4. Tropopause temperature has little effect upon any of the other variables.

and the values for the proposed values.
On the basis of the values of the coefficients
calculated from the values obtained from the
calculated and proposed coefficients, these values
are the following coefficients:

1. The pressure of the 2 atmosphere level was a
positive effect on the values pressure and the mean
temperature. It is very clearly and positively
correlated with temperature values, but it is not certain
whether it is an effect or effect. It has a negative
effect upon temperature values.

2. The temperature of the air column from 1 to 5
atmosphere has a negative effect upon values pressure,
a large positive effect upon the pressure at the 2
atmosphere level, no direct effect upon temperature values
and a moderate positive effect upon temperature values.

3. Temperature values has a negative effect upon
values pressure, no direct effect upon the mean temperature,
it is clearly correlated with the pressure at
the 2 atmosphere level, and has a very distinct negative
effect upon temperature values.

4. Temperature values has little effect upon
any of the other variables.

III. Investigations of E. Palmen

The object of this study was to attempt to couple the important temperature and pressure variations in the lower stratosphere with the tropospheric distribution of these two variables. In this connection Palmen studied the effect of both thermal-advection and dynamic convection in relation to the coupling sought.

Palmen elected, as a means of investigating the advective process, to study the results of soundings made on both sides of the polar front. On one side he had Polar air, on the other, tropical maritime air. These soundings showed a temperature difference of about 15 degrees C. between the two air masses, this temperature difference attained its maximum value between the 4 and 7 kilometer levels. The tropopause in the polar air mass was around the 8 kilometer level, that in the tropical air around 12 kilometers. The temperature difference again became large in the vicinity of the 12 kilometer level; however, this difference was in a reverse order to the former, i.e., where the temperature of the tropical air had been higher in the troposphere, it was lower than that of the polar air, in

121. Investigations of the

The object of this study was to ascertain the effect of the important temperature and pressure variations in the lower atmosphere with the propagation of sound. In this connection, the effect of both thermal-expansion and dynamic compression in relation to the sound wave was studied, as a means of investigating the advective process, to study the results of sound waves on both sides of the point of contact. On one side the point of contact, on the other, tropical weather air. These experiments showed a temperature difference of about 10 degrees F. between the two air masses, this temperature difference being the maximum value between the 4 and 5 kilometer levels. The temperature in the point of contact was found to be 10 kilometers level, that in the tropical air found to be 10 kilometers. The temperature difference again became large in the vicinity of the 10 kilometer level; however, this difference was in a reverse order to the above, i.e., where the temperature of the tropical air was found higher in the troposphere, it was lower than that of the point air, in

the stratosphere. Having obtained these results Palmén then proceeds to seek a coupling between the Polar front waves at the surface and the tropopause height changes.

In the explanation of the coupling effect he parallels his ideas with those of Bjerknes. A wave is assumed to have formed on the polar front. The tropical air glides upward on the West side of all wave crests and downward on their East side. This forced vertical motion must die away with elevation, and it is known that it almost disappears at the tropopause. Accordingly, there is vertical shrinking over the West side of the polar front wave crests and corresponding horizontal divergence of the tropical air; on the East side, on the contrary, there is vertical expansion and horizontal convergence. The direct result of horizontal divergence is acceleration of anti-cyclonic circulation and the consequence of convergence is acceleration of cyclonic circulation. The original purely west-east flow of tropical air will therefore assume an anti-cyclonic curvature over the western slopes of the wave crests and a cyclonic curvature over the eastern slopes of the wave crests. The stream lines acquire a sinusoidal like shape in the horizontal - a shape which is also taken up by the isobars. The eventual resultant effect is to have a raising of the tropopause height over the part of the

The atmosphere. Having obtained these results, I then proceed to show a working between the two types of the surface and the proposed height changes. In the explanation of the working effect in practice, his ideas will show in a moment. I now intend to have formed on the paper sheet. The proposed air lines spread on the back side of all the sheets and continued on their back side. This forces vertical motion most the way with elevation, and it is known that it is almost impossible at the proposed. Accordingly, there is vertical stretching over the back side of the paper from wave crests and corresponding horizontal divergence of the tropical air; on the back side, on the contrary, there is vertical expansion and horizontal convergence. The direct result of horizontal divergence is acceleration of anti-cyclonic circulation and the reverse of convergence is acceleration of cyclonic circulation. The original purely east-west flow of tropical air will therefore become an anti-cyclonic movement over the eastern slopes of the wave crests and a cyclonic movement over the western slopes of the wave crests. The stream lines appear as rounded lines above in the horizontal - a shape which is also seen up to the present. The eventual resulting effect is to have a series of the proposed belts over the part of the

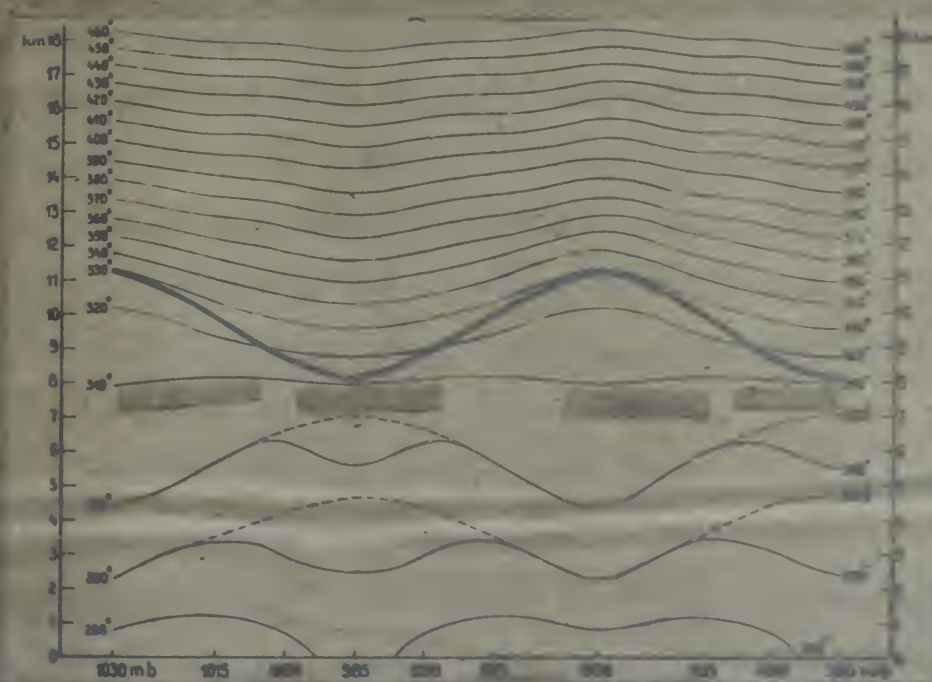
flow with the northerly component, a sinking over that part of the flow with the southerly component. In the stratosphere is found, in turn, a vertical stretching and a vertical shrinking, in conjunction with the shrinking and stretching described above. The tropopause wave was found to be out of phase with the polar front wave, in that its corresponding amplitude points are to the westward of those on the surface.

Having reached this stage by means of thermal advection Palmen then demonstrates how the action of dynamic convection becomes the controlling factor.

The vertical motion is augmented by the increase of vorticity as the cyclone becomes more intense and occludes. The vertical shrinking is accompanied by a convergence of the potential temperature surfaces, the region of vertical stretching is accompanied by a divergence of the potential temperature surfaces with a convergence of these surfaces above the regions of stretching. In the regions of convergence we have a decrease of the temperature gradient. The action of the above is illustrated in the following sketch. (See Page 9). The positions of the points of maximum convergence represent the position of the tropopause in these regions.

Palmen further states that if the convergence of the potential temperature surfaces is super-

Thus with the ordinary component, a similar over the
part of the line with the ordinary component. In the
arrangement is found, in fact, a vertical separation
and a vertical distance, in connection with the
condition and separating distance above. The program
must not be out of phase with the other lines
way, in that the corresponding significant points are so
the position of those of the system.
The vertical distance this way of phase of the
distance from the distance has the same of
distance between the controlling system.
The vertical distance is measured by the in-
crease of velocity as the system becomes more intense
and smaller. The vertical distance is measured by
a comparison of the potential energy between the
level of vertical distance is measured by a given
level of the potential energy between with a
movement of these curves above the point of which
effect. In the system as measured to have a distance
of the complete distance. The system at the level is
illustrated in the following figure. (See Fig. 2)
position of the system of minimum distance between
the position of the system in these figures.
The system shows that if the system
level of the potential energy between is equal





imposed on the existing tropopause, it will cause the normal inversion found in this region to sharpen. He obtains three general types of temperature - height curves extending up into the stratosphere - or "tropopause types" - as are shown on the following sketch. (See page 11). For normal pressure, in this case 1007 millibars, is found an isothermal situation starting at the tropopause; for low pressure at the surface, 976 millibars, is found a sharp inversion of a depth of about 1 kilometer and then a gradual decrease of temperature with height; for high pressures at the surface, 1034 millibars, is found a sharp inversion which extends several kilometers and then becomes practically isothermal.

If the action of the deformation field is such that the convergence of the potential temperature surfaces takes place other than at the tropopause itself, then, Palmen asserts, a new tropopause is formed at this region of convergence and the old tropopause is annihilated. The formation of this new tropopause, in sections, at varying heights, gives a leaf-like structure, instead of a continuous smooth boundary surface. Turbulent mixing takes place between the open discontinuities of the new tropopause structure.

From the investigations and results as outlined above, Palmen arrives at the following conclusions:

These three, which appear in the following conclusions:

From the investigation and results are con-

clusions are:

1. The first is the open characteristics of the

continuous wave boundary surface. The first is the

the surface, the surface is the surface, the surface is the

the surface of the surface, the surface is the surface of the

surface of the surface, the surface is the surface of the

surface, the surface is the surface of the surface of the

surface, the surface is the surface of the surface of the

surface, the surface is the surface of the surface of the

surface, the surface is the surface of the surface of the

surface, the surface is the surface of the surface of the

surface, the surface is the surface of the surface of the

surface, the surface is the surface of the surface of the

surface, the surface is the surface of the surface of the

surface, the surface is the surface of the surface of the

surface, the surface is the surface of the surface of the

surface, the surface is the surface of the surface of the

surface, the surface is the surface of the surface of the

surface, the surface is the surface of the surface of the

surface, the surface is the surface of the surface of the

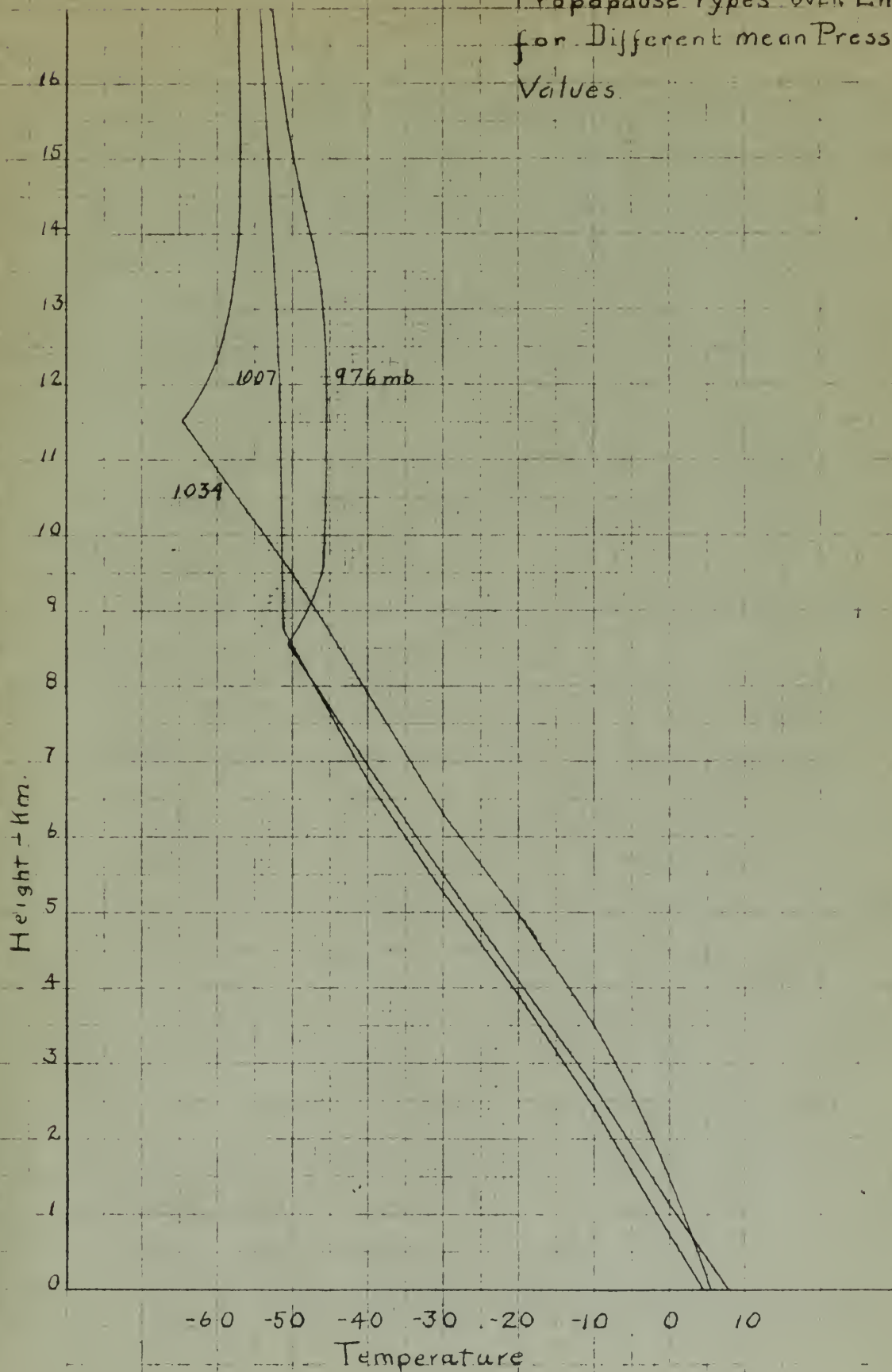
surface, the surface is the surface of the surface of the

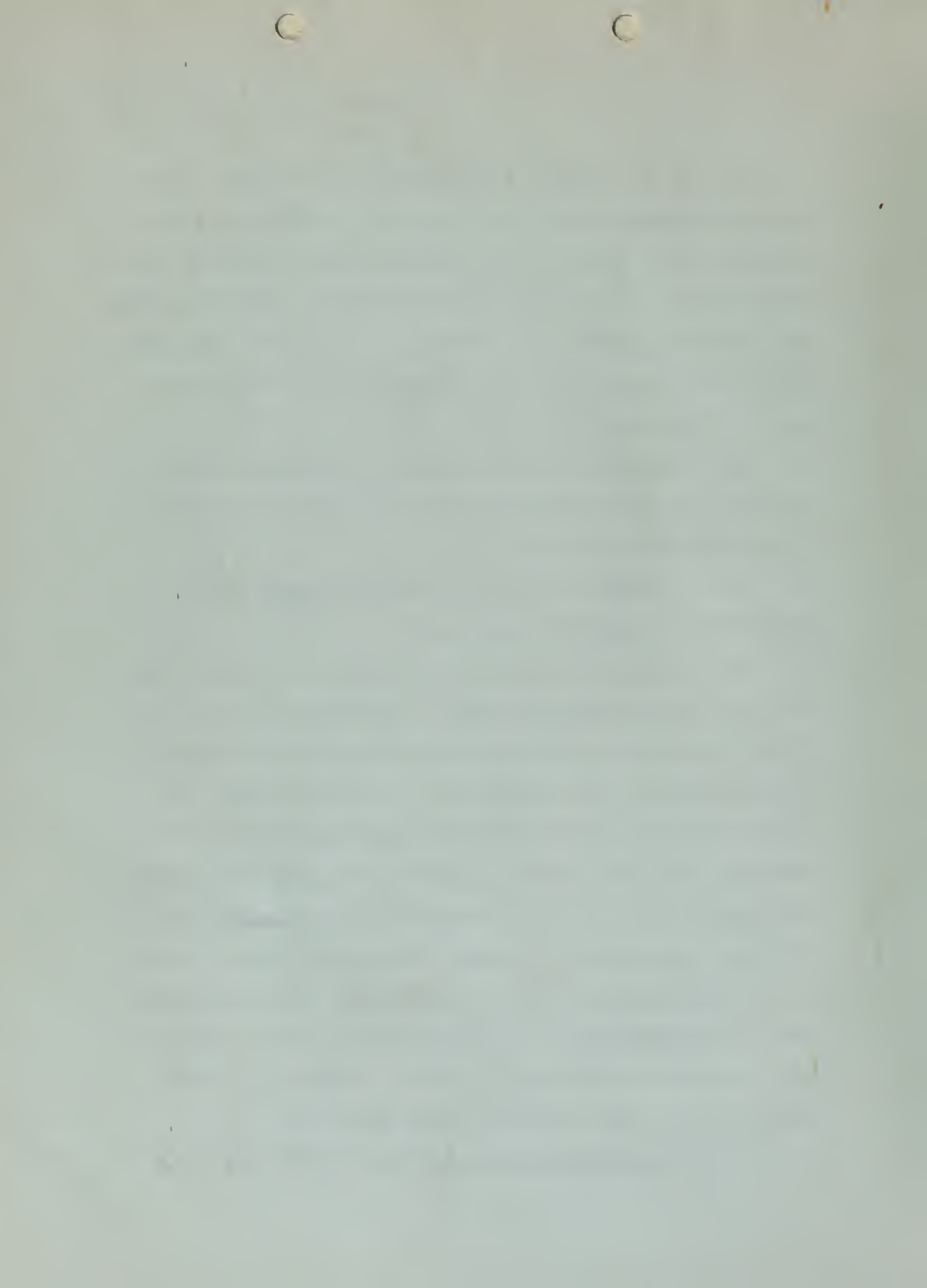
surface, the surface is the surface of the surface of the

surface, the surface is the surface of the surface of the

surface, the surface is the surface of the surface of the

Tropopause Types OVER England
for Different mean Pressure
Values.





1. In the primary development of a cyclone, advection dominates, in that the temperature changes in the main can be attributed to meridional advection - in this stage, polar front waves and tropopause waves are coupled in a certain phase displacement. The general tropopause and stratosphere advection represents a unified atmospheric flow pattern.

2. Investigation of temperature contrasts between tropical air and polar air gives the best means of study of meridional advection.

3. At times the frontal surface extends to the upper boundary of the tropopause.

4. As occlusion sets in a cyclone the dynamically vertical displacement dominates, in that, from this stage on, the temperature and pressure changes depend, in the main, on the vortification of the cyclone. A closer analysis of these temperature changes and of the vertical oscillations of the tropopause that one has to deal with, with the attendant deformation fields, show that not only tropopause types may change, but in certain cases the tropopause itself. From this it follows that the actually occurring vertical action in a so-called tropopause front may not always be determined from the oscillation of the apparent tropopause.

6. By investigating typical individual cases as



1. In the primary development of a cyclone, advection dominates, in that the temperature changes in the main can be attributed to meridional advection - in this stage, polar front waves and tropopause waves are coupled in a certain phase displacement. The general tropopause and stratosphere advection represents a unified atmospheric flow pattern.

2. Investigation of temperature contrasts between tropical air and polar air gives the best means of study of meridional advection.

3. At times the frontal surface extends to the upper boundary of the tropopause.

4. As occlusion sets in a cyclone the dynamically vertical displacement dominates, in that, from this stage on, the temperature and pressure changes depend, in the main, on the vortification of the cyclone. A closer analysis of these temperature changes and of the vertical oscillations of the tropopause that one has to deal with, with the attendant deformation fields, show that not only tropopause types may change, but in certain cases the tropopause itself. From this it follows that the actually occurring vertical action in a so-called tropopause front may not always be determined from the oscillation of the apparent tropopause.

6. By investigating typical individual cases as

well as through the formation of suitable mean values the influences of the fields of deformation of the temperature distribution in the environment of the tropopause over cyclones and anti-cyclones becomes quite clear. Over strong cyclones and occlusions the tropopause is generally characterized by a sharp inversion. This is also the case over anti-cyclones. There is an important difference in that the tropopause is low over cyclones and high over anti-cyclones. Also the tropopause inversion over cyclones covers about 1 kilometer while the inversion is several kilometers deep over anti-cyclones. At normal pressure the lower stratosphere over Europe is characterized by particularly isothermal stratification.

7. By the distribution of potential temperature one can, by omitting radiation and advection, in certain cases compute the vertical displacements which actually took place in the generation of highs and lows.

8. The question of the seat of atmospheric pressure variations can be answered only on the basis of detailed analysis of the phenomena at different levels. It is true that in general the stratosphere phenomena, on the face of it, have a deciding influence on the pressure variations below. But this fact depends on the general thermal structure of the atmosphere and has nothing to do with the problem of cause and effect.

well as through the formation of minute sea waves
the influence of the fields of deformation of the
interior circulation in the movement of the
troposphere over cyclones and anti-cyclones becomes quite
clear. Over strong cyclones and depressions the tropo-
sphere is generally characterized by a sharp inversion.
This is also the case over anti-cyclones. There is an
important difference in that the troposphere is low over
cyclones and high over anti-cyclones. Also the tropo-
sphere inversion over cyclones occurs about 1 mile
lower than the inversion in several thousand days
over anti-cyclones. At several thousand days the
inversion over cyclones is characterized by a sharp
inversion.

7. By the distribution of potential temperature
one can, by analyzing circulation and movement, in certain
cases compute the vertical displacement of the surface
of the sea in the movement of high and low.
8. The position of the axis of atmospheric pressure
variations can be computed only on the basis of detailed
analysis of the pressure at different levels. It is
true that in general the atmospheric pressure, in
the face of it, does not depend on the pressure
variations below. But this does depend on the general
thermal structure of the atmosphere and has nothing to
do with the position of axes and others.

IV. Analysis of Conditions Over Stations in the U.S.

The greatest obstacle to the proper development of this subject is the lack of sounding balloon ascents, not so much in quantity, but scarcity of soundings made at regular intervals over a period of time when large temperature and pressure variations are to be encountered. Also it was essential to use soundings which had been evaluated in a manner such that temperature, pressure, and elevation could be selected for a great number of points without having to recompute the soundings. The most desirable series of soundings were obtained for the stations listed below:

- | | |
|------------------------|-----------|
| 1. Royal Center, Ind. | May 1926 |
| 2. Grosbeck, Texas | Oct. 1927 |
| 3. Broken Arrow, Okla. | Dec. 1929 |
| 4. Royal Center, Ind. | Sep. 1930 |
| 5. Royal Center, Ind. | Feb. 1931 |

This information was obtained from the various Monthly Weather Reviews.

All seasons except the summer are represented in this group, in addition there is a variation of latitude between the extreme stations of about ten degrees. Since some of the groups evaluated by Dines consisted of

IV. RESULTS OF INVESTIGATION

The present condition of the power plant and of this subject in the case of existing business, and as well in quantity, the quality of materials and as regular intervals over a period of time have been determined and various conditions and as determined. Also it was determined to see whether or not the power plant is a sound one, and whether or not the plant is in a position to be able to do a great deal of business. The points of view having in view the condition of the plant and the results of the investigation were checked by the various figures.

1. Power plant, Ind.	1911
2. Power plant, Tex.	1912
3. Power plant, Okla.	1913
4. Power plant, Ind.	1914
5. Power plant, Ind.	1915

The investigation was conducted from the results of the various figures.

All figures were obtained from the various sources in this case, in which there is a variation of fact and between the various figures of the various sources. The results of the investigation by the various sources of the various figures.

soundings made throughout the year and at various stations in Europe, it is believed that reliable results can be obtained from the above stations.

It was necessary to select a system of grouping the soundings in pairs such that the maximum number could be obtained, since it was believed that satisfactory mean values could not be established accurately for the monthly periods. The groupings consisted in determining the changes between two subsequent soundings where the time interval between the two was not less than eight hours and not more than thirty hours. This irregular time interval was necessary because of the fact that the balloons were not released at constant intervals, a few of the records were lost or destroyed, and some of the soundings extended only a few kilometers above sea level.

In many of the soundings it was extremely difficult to determine the tropopause height, necessitating the formulation of an arbitrary definition for this height. The method used by Dines was selected, in which he defines the tropopause height as the highest point where the temperature decrease is less than one degree per kilometer. By adhering to a rule of this sort there is a tendency to eliminate all low inversions one of which may be the tropopause with a considerable

temperature decrease above the inversion. Therefore the results obtained by using tropopause heights and temperatures, cannot be judged so much by their numerical values but certainly the signs of the correlation coefficients should be correct.

The soundings were grouped for each station into pairs as explained above and the time variation of the various elements obtained. From these differences the standard deviations were computed by the formula

$$\sigma = \sqrt{\frac{\sum (\delta_a)^2}{n}} .$$

The values of the standard deviations are listed below:

Ps	4.5 mb.
Tm	3.4°C.
Pg	4.4 mb.
Hc	1370 m.
Tc	6.1°C.

By comparing the standard deviations with the individual differences no ratio of the two was greater than 2.5 which shows that the material selected was very uniform.

The correlation coefficients were calculated from the standard deviations by means of the formula:

temperature decrease above the inversion. Therefore the results obtained by using temperature heights and temperature

heights cannot be taken as proof of their numerical values but certainly the sign of the correlation coefficient should be correct.

The readings were grouped for each station into pairs as explained above and the time variation of the various elements obtained. From these differences the standard deviations were computed by the formula

$$\sigma = \sqrt{\frac{\sum d^2}{n}}$$

The values of the standard deviations are listed below

12	4.5
13	3.5
14	4.5
15	1.5
16	1.5

By comparing the standard deviations with the individual differences in pairs of the two are found that 2.5 inch above the surface is related with very uniform

The correlation coefficients were calculated from the standard deviations of each of the elements

$$r_{a,b} = \frac{\sum (\delta_a \delta_b)}{\sqrt{\sum (\delta_a)^2 \sum (\delta_b)^2}}$$
 where a, and b represent the variables being correlated. The correlation coefficients are listed below in addition to those obtained by Dines.

<u>Number of</u> <u>Combinations</u>	<u>Items</u> <u>Correlated</u>	<u>Correlation</u> <u>Coefficients</u>	<u>Mean Correlation</u> <u>Coefficients-Dines</u>
82	r _{1,2}	-.30	.46
80	r _{1,3}	.12	.66
52	r _{1,4}	.14	.69
52	r _{1,5}	.11	(-).59
80	r _{2,3}	.70	.92
52	r _{2,4}	.35	.78
52	r _{2,5}	(-).16	(-).39
52	r _{3,4}	.25	.83
52	r _{3,5}	(-).04	(-).49
52	r _{4,5}	(-).67	(-).65

- 1 = Surface Pressure
- 2 = Mean Temperature 1 - 9 km.
- 3 = Pressure 9 km.
- 4 = Height Tropopause
- 5 = Temperature Tropopause.

It will be noted that wherever Hc or Tc is involved as one of the variables, the number of groupings decreases. This is due to the fact that many of the soundings did not extend up to the tropopause.

where λ and μ represent the
 variables being correlated. The correlation coefficients
 are listed below in addition to those obtained by direct

Number of Combinations Formed	Form	Inversion	Form Inversion
1	1	1	1
2	2	2	2
3	3	3	3
4	4	4	4
5	5	5	5
6	6	6	6
7	7	7	7
8	8	8	8
9	9	9	9
10	10	10	10
11	11	11	11
12	12	12	12
13	13	13	13
14	14	14	14
15	15	15	15
16	16	16	16
17	17	17	17
18	18	18	18
19	19	19	19
20	20	20	20
21	21	21	21
22	22	22	22
23	23	23	23
24	24	24	24
25	25	25	25
26	26	26	26
27	27	27	27
28	28	28	28
29	29	29	29
30	30	30	30
31	31	31	31
32	32	32	32
33	33	33	33
34	34	34	34
35	35	35	35
36	36	36	36
37	37	37	37
38	38	38	38
39	39	39	39
40	40	40	40
41	41	41	41
42	42	42	42
43	43	43	43
44	44	44	44
45	45	45	45
46	46	46	46
47	47	47	47
48	48	48	48
49	49	49	49
50	50	50	50
51	51	51	51
52	52	52	52
53	53	53	53
54	54	54	54
55	55	55	55
56	56	56	56
57	57	57	57
58	58	58	58
59	59	59	59
60	60	60	60
61	61	61	61
62	62	62	62
63	63	63	63
64	64	64	64
65	65	65	65
66	66	66	66
67	67	67	67
68	68	68	68
69	69	69	69
70	70	70	70
71	71	71	71
72	72	72	72
73	73	73	73
74	74	74	74
75	75	75	75
76	76	76	76
77	77	77	77
78	78	78	78
79	79	79	79
80	80	80	80
81	81	81	81
82	82	82	82
83	83	83	83
84	84	84	84
85	85	85	85
86	86	86	86
87	87	87	87
88	88	88	88
89	89	89	89
90	90	90	90
91	91	91	91
92	92	92	92
93	93	93	93
94	94	94	94
95	95	95	95
96	96	96	96
97	97	97	97
98	98	98	98
99	99	99	99
100	100	100	100

1 = Number of combinations
 2 = Number of combinations
 3 = Number of combinations
 4 = Number of combinations
 5 = Number of combinations
 6 = Number of combinations
 7 = Number of combinations
 8 = Number of combinations
 9 = Number of combinations
 10 = Number of combinations
 11 = Number of combinations
 12 = Number of combinations
 13 = Number of combinations
 14 = Number of combinations
 15 = Number of combinations
 16 = Number of combinations
 17 = Number of combinations
 18 = Number of combinations
 19 = Number of combinations
 20 = Number of combinations
 21 = Number of combinations
 22 = Number of combinations
 23 = Number of combinations
 24 = Number of combinations
 25 = Number of combinations
 26 = Number of combinations
 27 = Number of combinations
 28 = Number of combinations
 29 = Number of combinations
 30 = Number of combinations
 31 = Number of combinations
 32 = Number of combinations
 33 = Number of combinations
 34 = Number of combinations
 35 = Number of combinations
 36 = Number of combinations
 37 = Number of combinations
 38 = Number of combinations
 39 = Number of combinations
 40 = Number of combinations
 41 = Number of combinations
 42 = Number of combinations
 43 = Number of combinations
 44 = Number of combinations
 45 = Number of combinations
 46 = Number of combinations
 47 = Number of combinations
 48 = Number of combinations
 49 = Number of combinations
 50 = Number of combinations
 51 = Number of combinations
 52 = Number of combinations
 53 = Number of combinations
 54 = Number of combinations
 55 = Number of combinations
 56 = Number of combinations
 57 = Number of combinations
 58 = Number of combinations
 59 = Number of combinations
 60 = Number of combinations
 61 = Number of combinations
 62 = Number of combinations
 63 = Number of combinations
 64 = Number of combinations
 65 = Number of combinations
 66 = Number of combinations
 67 = Number of combinations
 68 = Number of combinations
 69 = Number of combinations
 70 = Number of combinations
 71 = Number of combinations
 72 = Number of combinations
 73 = Number of combinations
 74 = Number of combinations
 75 = Number of combinations
 76 = Number of combinations
 77 = Number of combinations
 78 = Number of combinations
 79 = Number of combinations
 80 = Number of combinations
 81 = Number of combinations
 82 = Number of combinations
 83 = Number of combinations
 84 = Number of combinations
 85 = Number of combinations
 86 = Number of combinations
 87 = Number of combinations
 88 = Number of combinations
 89 = Number of combinations
 90 = Number of combinations
 91 = Number of combinations
 92 = Number of combinations
 93 = Number of combinations
 94 = Number of combinations
 95 = Number of combinations
 96 = Number of combinations
 97 = Number of combinations
 98 = Number of combinations
 99 = Number of combinations
 100 = Number of combinations

It was believed that the extreme smallness of most of the correlation coefficients might be due to the method of grouping together stations in different latitudes and for different seasons of the year. Several of the individual months were grouped separately but the correlation coefficients obtained from these groups were of about the same magnitude as those found for the entire group, so that the correlation coefficients calculated from the entire group were accepted as being representative of the atmosphere over the United States.

The correlations which are of chief interest to synoptic meteorologists are those which may be deduced from surface observations. From the table it may be seen that surface pressure has a fair negative correlation with the mean temperature but practically no correlation with any of the other elements. This brings out very strikingly the independence of surface pressure. This is in direct opposition to the results obtained by Dines as may be noted from an inspection of the tables above. This difference may be explained by considering the disturbances observed over the United States and Europe. As a general rule cyclones and anticyclones occurring over Europe are very deep, well-developed disturbances, which in many instances are believed to extend well into the stratosphere.

It is believed that the various countries of the world are not only in the process of becoming more and more democratic, but also more and more united. This is in spite of the fact that the world is still a very long way from being a single entity. The various countries are still in the process of becoming more and more democratic, but they are also becoming more and more united. This is in spite of the fact that the world is still a very long way from being a single entity. The various countries are still in the process of becoming more and more democratic, but they are also becoming more and more united. This is in spite of the fact that the world is still a very long way from being a single entity.

Over the United States most of the surface disturbances are comparatively shallow and move fairly rapidly. This is apparent from the atmospheric cross-sections made at M.I.T. during the past winter.

The only marked agreement between the correlation coefficients of Dines and those obtained for the United States are those between mean temperature and the pressure at the 0 kilometer level, and between the tropopause height and the temperature at the tropopause. It is seen that with a high pressure at the 0 kilometer level there is a corresponding large increase in the mean temperature of the column of air under this level and for a low temperature at the 0 kilometer there exists a low mean temperature of the air column. This warming and cooling is of such a magnitude that it cannot be explained by this change of pressure so that other explanations had to be sought which are incorporated in that part of the investigation following the methods of Palmén. It is also seen that with a high tropopause there exists cold temperatures and with a low tropopause there exists warm temperatures. More detailed discussion of this condition will be given on the following pages.

There are three main types of the modern skyscraper: the office building, the hotel, and the apartment house. The office building is the most common type, and it is the one that has the most influence on the city's skyline. The hotel is the second most common type, and it is the one that has the most influence on the city's economy. The apartment house is the third most common type, and it is the one that has the most influence on the city's social structure.

Potential Temperature Surfaces in the Vicinity of the Tropopause and Tropopause Types Obtained from this Distribution Paralleling the Methods of Falmen.

The first step in the study of the distribution of potential temperature surfaces in the vicinity of the tropopause was to obtain correlation coefficients between the pressure at the 9 kilometer level and the heights of specific potential temperature surfaces. In selecting potential temperature surfaces it was deemed expedient to select surfaces close enough to the tropopause so that the contour of the latter could easily be compared to the contour of the former. At the same time it was necessary to use a range of surfaces which would clearly indicate any convergence or divergence and important temperature variations.

The material used consisted of the records for September 1930 and February 1931 for Royal Center, Indiana and for December 1929 at Broken Arrow, Oklahoma. The values for these correlation coefficients are tabulated on page 21.

potential temperature contours in the vicinity of the
tropopause and tropopause type changes from this data
distribution revealing the nature of the

The first step in the study of the distribu-
tion of potential temperature contours in the vicinity
of the tropopause was to obtain correlation coefficients
between the pressure at the 5 kilometer level and the
height of specific potential temperature surfaces. In
selecting potential temperature surfaces it was deemed
expedient to select surfaces close enough to the tropo-
pause so that the contour of the latter could easily be
compared to the contour of the former. At the same time
it was necessary to use a range of surfaces which would
directly indicate any convergence or divergence and the
resulting temperature variations.

The potential level selected of the surfaces
for December 1950 and February 1951 for April 1951,
October and for December 1950 as shown above, indicates
the values for these correlation coefficients are tabu-
lated on page 21.

BROKEN ARROW - DECEMBER 1929

θ	r	T_{mean}	P_{mean}	Number of Pairs
315	(-) .91	6,740	313	21
325	+ .31	9,395	310	16
335	+ .74	11,010	310	14
365	+ .81	13,200	309	13

ROYAL CENTER - SEPTEMBER 1930

320	(-) .53	5,620	323	24
335	(-) .40	9,300	324	17
350	+ .15	12,460	322	18
365	+ .65	13,820	324	15

ROYAL CENTER - FEBRUARY 1931

300	(-) .76	4,540	302	27
310	(-) .25	8,090	302	22
320	+ .28	9,960	302	20
330	+ .59	11,050	302	20
340	+ .74	11,510	302	18
360	+ .67	12,760	302	16

The number of pairs of soundings available for the individual months range from 27 for the lower surface to 13 for the extreme value of potential temperature. It is unfortunate that more soundings in sequence could not have been obtained, however, it is believed that they are adequate for the investigation at hand. A very consistent range of correlation coefficients was obtained for each individual month, being negative for low poten-

tial temperature values and positive for high potential temperatures. The magnitude of the correlation coefficients are large for the extreme values of potential temperature.

In order to show graphically the points brought out by the correlation coefficients, a plot of the pressure at the 9 kilometer level was made against the height of potential temperature surfaces. Over the low pressure there is a marked concentration of potential temperature surfaces. Over the high the tropopause is much higher and it has increased its potential temperature by some 20 degrees.

The curves discussed in this paragraph and those that follow will be found grouped by stations on pages 24,25,26,27,28,29,

In order to obtain the best average position for the tropopause, regression equations were deduced and regression lines for the various potential temperatures. These were superimposed on their respective potential temperature curves on the pressure-height plot.

The regression equation used was:

$$H = H_{\text{mean}} + r \sqrt{\frac{\sum (\delta h)^2}{\sum (\delta P_9)^2}} (P_9 - P_{9\text{mean}})$$

Characteristic temperature-height curves were plotted for the distribution of potential temperature regression lines for high, average, and low pressures at

that temperature values are positive for high potential
 temperatures. The magnitude of the correlation coefficient
 is also very large for the various values of potential

temperatures.

In order to show graphically the positive character
 of the correlation coefficient, a plot of the potential
 at the 0 kilometer level was made against the height of
 potential temperature difference. Over the low pressure
 there is a marked concentration of potential temperature
 values. When the high the temperature is much higher
 and it has increased the potential temperature by some
 30 degrees.

The curves obtained in this experiment and
 those for other will be found plotted by stations on
 page 24, 25, 26, 27, 28, 29.

In order to obtain the best possible position
 for the temperature, temperature differences were obtained
 and potential lines for the various potential differences
 were also obtained. These were represented as their respective
 potential differences in the temperature-height plot.
 The following equation was used:

$$\frac{1}{\rho} = \frac{1}{\rho_0} \left(1 - \frac{\alpha}{\rho_0} \right)$$

Characteristics temperature-height curves were
 plotted for the distribution of potential temperature
 between lines for high, average, and low pressure at

the 2 kilometer level. The equation used to establish the temperature at different levels was formed from Poisson's equation and the hydrostatic equation:

$$T = \theta \left[\frac{T_0}{T_0} - \frac{g}{C_p} \frac{(z - z_0)}{u_{\text{mean}}} \right] \quad \text{where } \theta = \text{Potential Temperature.}$$

These temperature-height curves show that definite characteristic types of the tropopause inversion exist over high and low pressure areas at the 3 kilometer level. A marked similarity will be noted for the three cases analyzed. The inversions over low pressure are several kilometers lower than the mean height of the tropopause and are marked by fairly steep lapse rates in the troposphere below this inversion. Above the inversion there is a gradual decrease of temperature continuing as far as the sounding was extended. The tropopause over the high was not marked by a large inversion but gave a small rate of increase of temperature in the stratosphere.

It is to be noted that the troposphere is about 5 degrees warmer under the high pressure than under the low. Above the tropopause the temperature over the high is considerably colder than that over the low. This distribution is exactly that found by Felsum, which has been accounted for by him through the influence of

the following level. The equation is as follows:

The equation of the level is as follows:

The equation of the level is as follows:

$$T = \frac{1}{2} \left[\frac{(1 - \frac{1}{2})}{\frac{1}{2}} \right] = \frac{1}{2} \left[\frac{1}{2} \right] = \frac{1}{4}$$

The equation of the level is as follows:

The equation of the level is as follows:

The equation of the level is as follows:

The equation of the level is as follows:

The equation of the level is as follows:

The equation of the level is as follows:

The equation of the level is as follows:

The equation of the level is as follows:

The equation of the level is as follows:

The equation of the level is as follows:

The equation of the level is as follows:

The equation of the level is as follows:

The equation of the level is as follows:

The equation of the level is as follows:

The equation of the level is as follows:

The equation of the level is as follows:

The equation of the level is as follows:

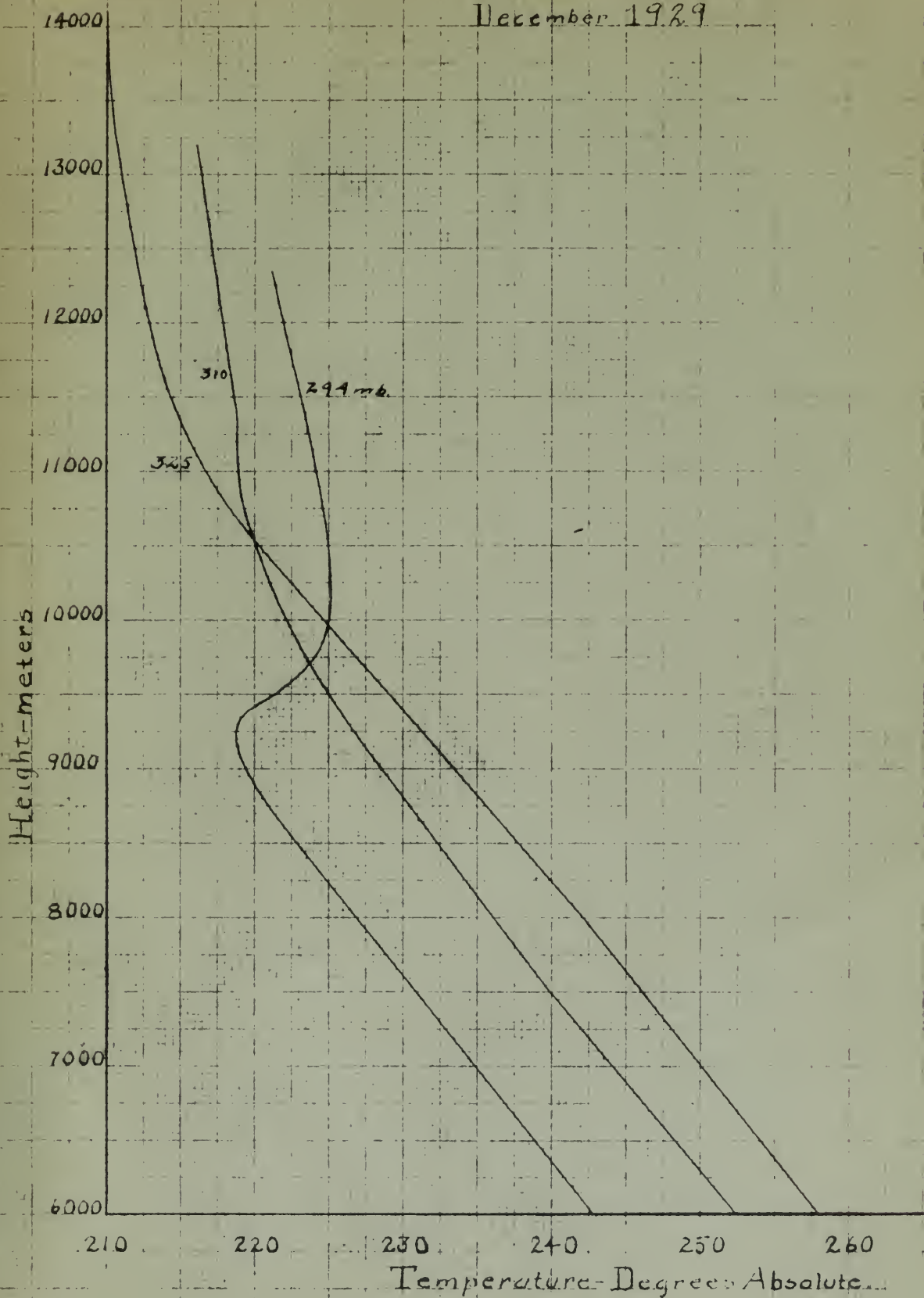
The equation of the level is as follows:

The equation of the level is as follows:

The equation of the level is as follows:

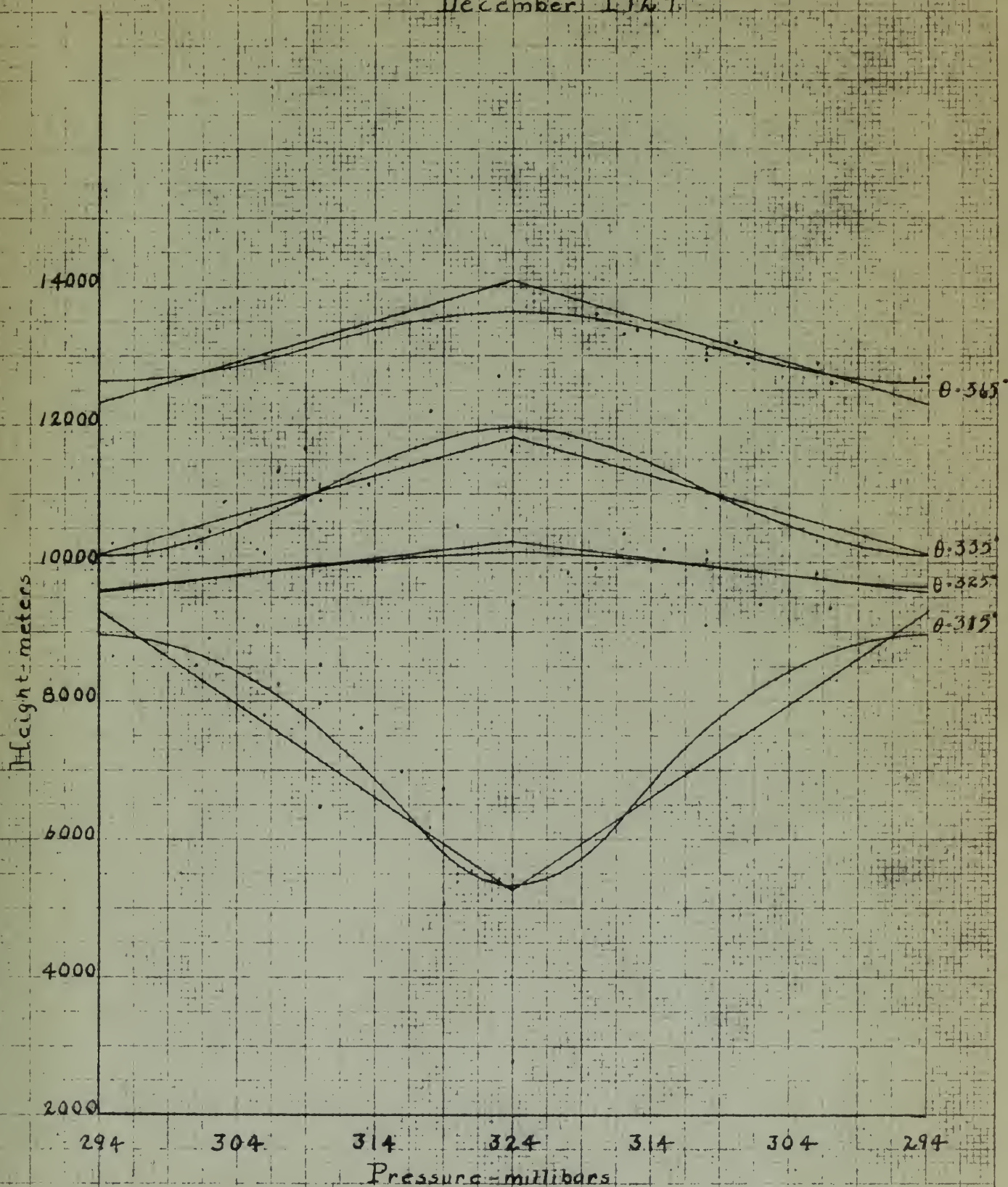
The equation of the level is as follows:

Temperature-Height Curves
Broken Arrow, Okla.
December 1929



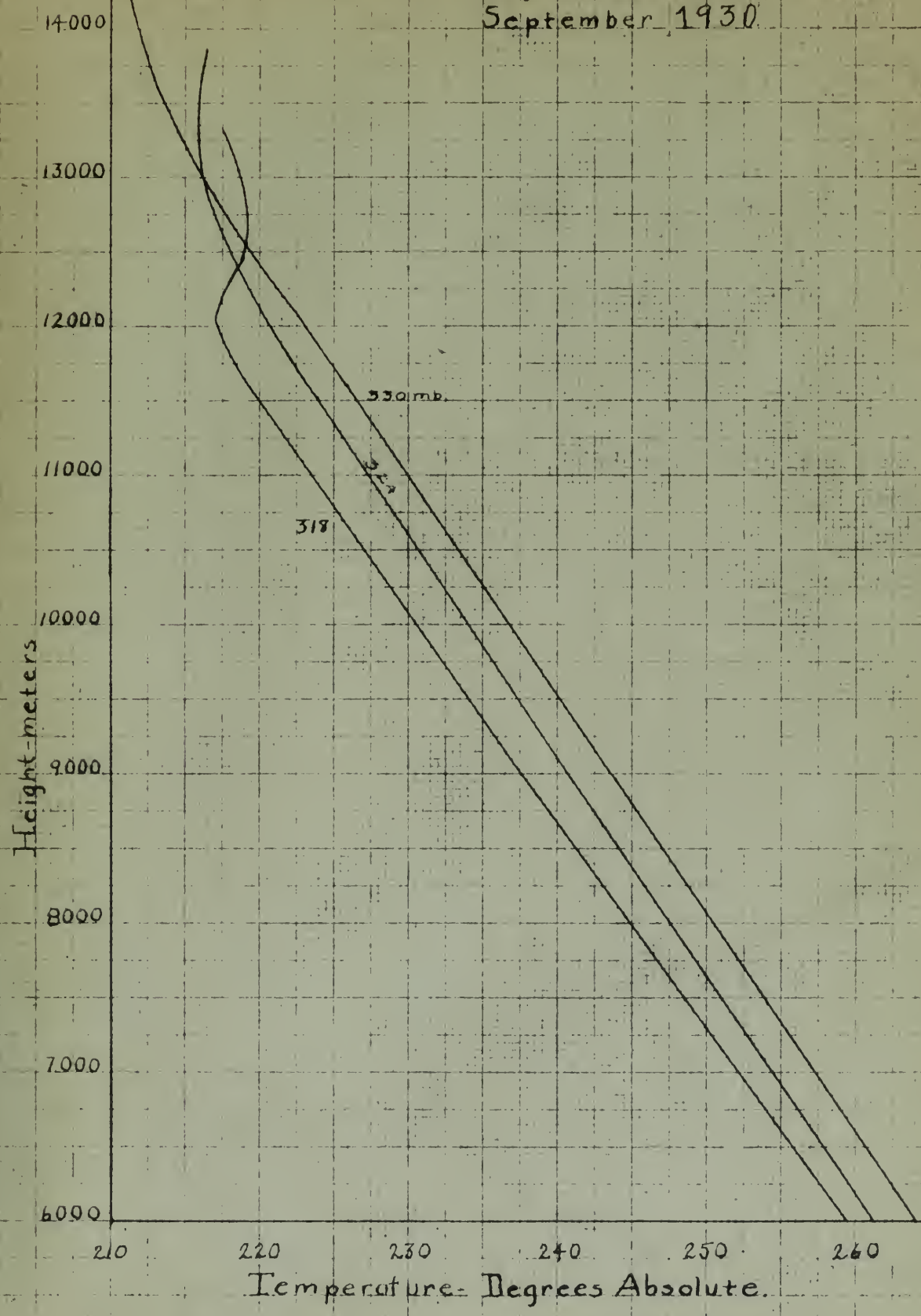


Pressure-Height Curves
Bronen Arrow, Okla.
December 1929



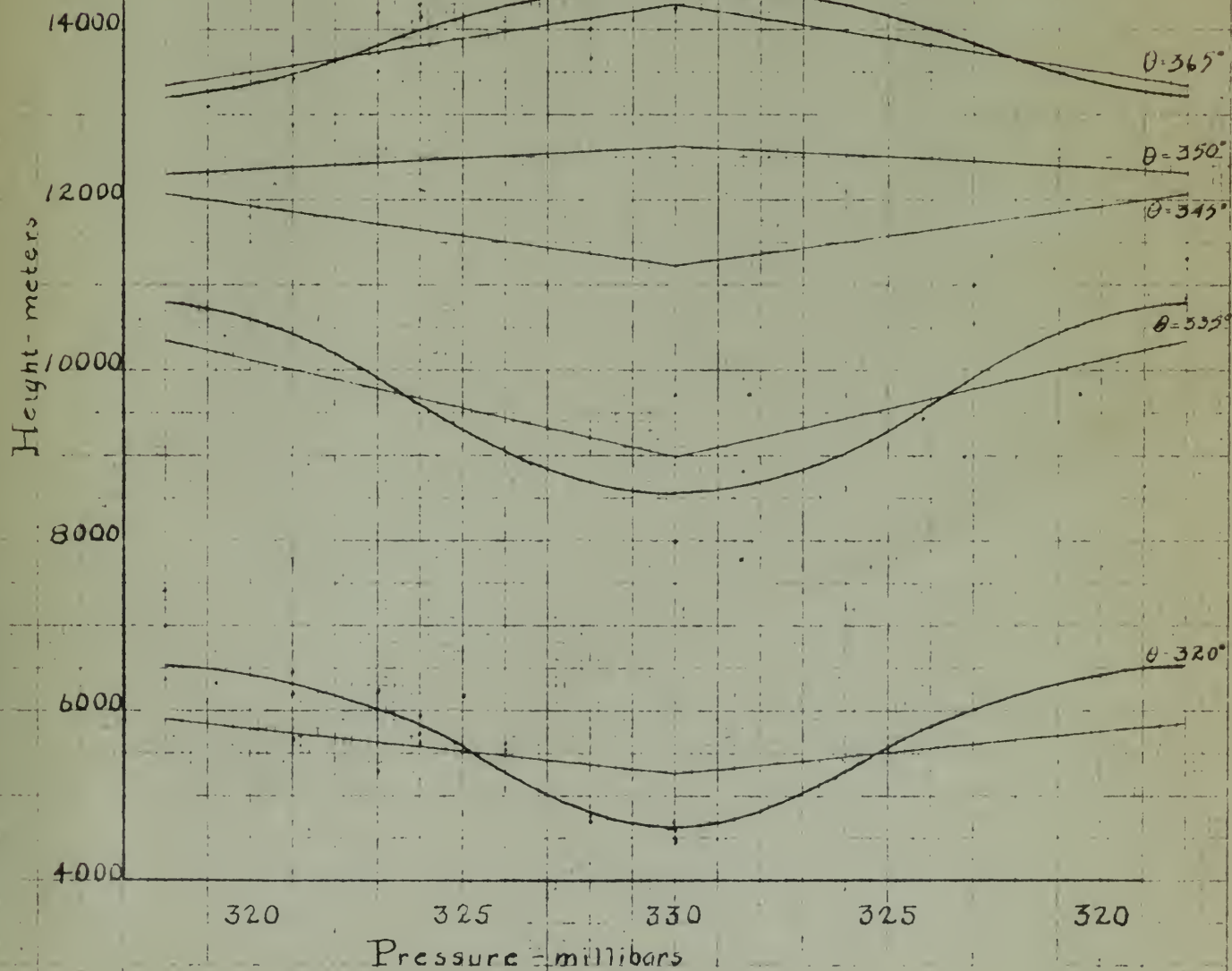


Temperature-Height Curves
Royal Center, Ind.
September 1930



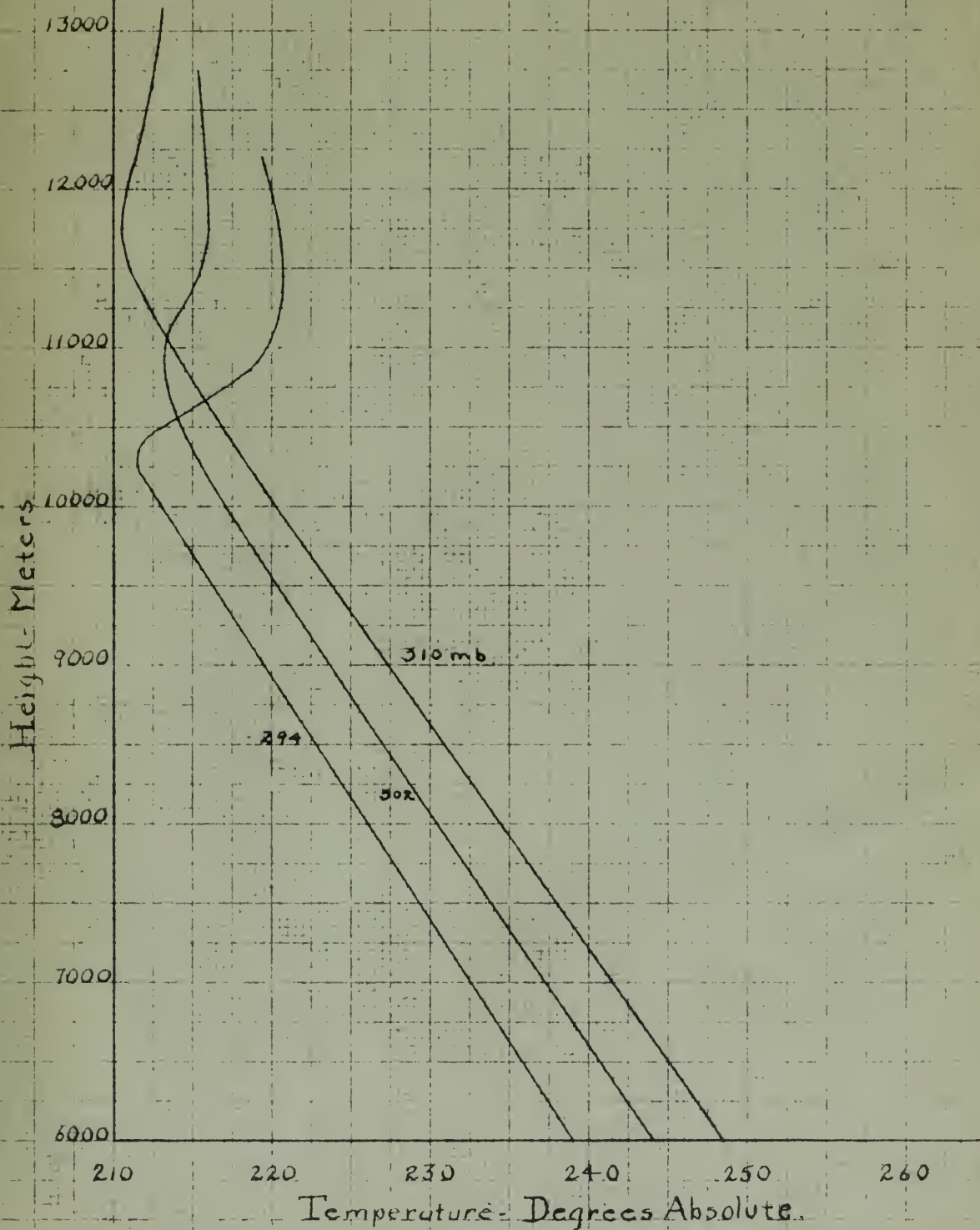


Pressure-Height Curves
Royal Center, Ind.
September 1930



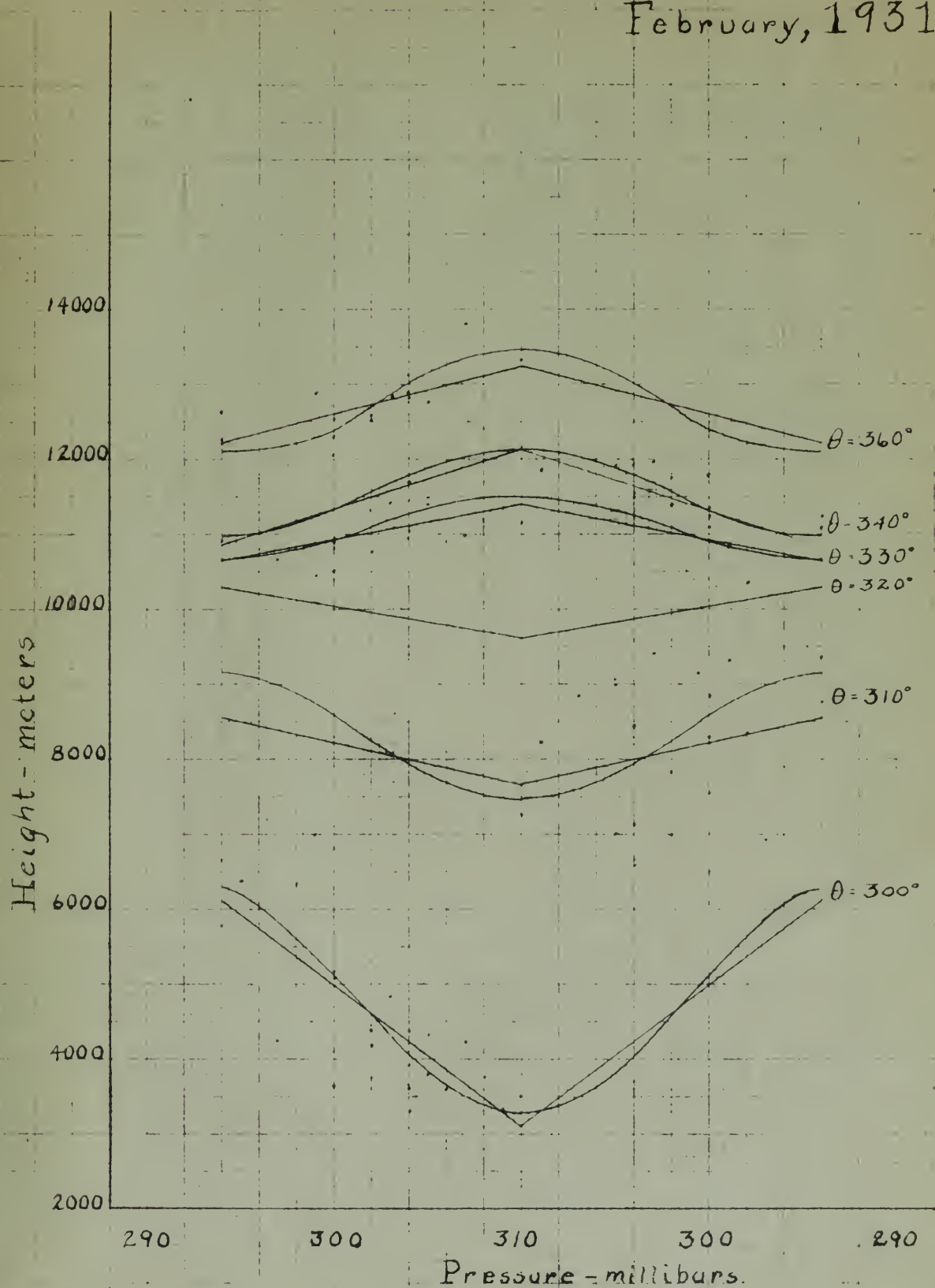


Temperature-Height Curves
February 1931
Royal Center, Ind.





Pressure - Height Curves
Royal Center, Ind.
February, 1931.





thermal-advective and dynamic processes as explained in the resume of his work.

From the above investigation the following conclusions have been drawn:

consequently, the dynamic processes as explained

in the terms of his work.

From the above investigation the following

conclusions have been drawn:

V. Summary

1. The contour of the potential temperature surfaces in the vicinity of the tropopause and in the stratosphere are very similar to the contour of the tropopause, while in the troposphere below the 9 kilometer level the slope of the former is opposite to that of the latter.

2. The existence of the tropopause types is substantiated by the distribution of the potential temperature surfaces. Over the low pressure area we have a well defined field of convergence, indicative of a region of great stability - over the high pressure area we find more equal spacing of the surfaces but, however, a gradual decrease in the distances between these surfaces - an indication of stability but to a lesser degree. The translation of the distribution of potential surfaces to a temperature versus height diagram shows in more detail the actual amount of stability represented.

3. The displacement of the concentration of potential temperature surfaces to a different level causes the regeneration of the tropopause at that level. We have a condition where the instantaneous height of the tropopause cannot be defined as existing at one

1.1. INTRODUCTION

1. The subject of the present investigation was the study of the relationship between the physical and the psychological factors in the determination of the human response to the environment. The study was carried out in the form of a series of experiments, the results of which are presented in the following chapters.

2. The relationship between the physical and the psychological factors in the determination of the human response to the environment is a complex one. It is the result of a number of factors, some of which are physical, some are psychological, and some are a combination of the two. The present investigation was carried out in order to determine the relative importance of these factors in the determination of the human response to the environment. The results of the investigation are presented in the following chapters.

3. The investigation of the relationship between the physical and the psychological factors in the determination of the human response to the environment is a complex one. It is the result of a number of factors, some of which are physical, some are psychological, and some are a combination of the two. The present investigation was carried out in order to determine the relative importance of these factors in the determination of the human response to the environment. The results of the investigation are presented in the following chapters.

height only. The shifting of the tropopause to different levels has its origin in the thermal-advective processes.

4. The tropopause height varies as the pressure at the 9 kilometer level. Little correlation exists between the pressure at the surface and that of the 9 kilometer level, hence there is little correlation between surface pressure and tropopause height. The transitory nature of the shallow-disturbances which traverse the United States would account for this variation from European conditions.

5. The tropopause type curves show definitely that the troposphere temperature for a high pressure at the 9 kilometer level is considerably higher than that for a low pressure at the same level. In the stratosphere the opposite effect is true, i.e., over the high it is colder than over the low. This distribution of temperature is accounted for primarily by advection but intensified in the vicinity of the tropopause by convection especially over a low pressure area.

6. An examination of the zonal distribution of pressure and temperature at different heights indicates that the conditions outlined as existing over the United States could be accounted for primarily by thermal-advective but that convection is required to complete the picture.

balise only. The falling of the temperature is different
but level is the same in the same direction
proposed.

4. The temperature level is the same as the pressure at
the 2 kilometer level. This is because the
from the pressure of the surface and that of the 2
kilometer level, there is a difference of
from surface pressure and temperature level. The
thermal level of the surface is different from
pressure the level of the surface for this reason
after the pressure level.

5. The temperature level is the same as the pressure at the
the pressure level for a high pressure at the
2 kilometer level is considerably higher than that for
a low pressure at the same level. In the atmosphere
the pressure level is high, i.e., over the high is in
order than over the low. This is because of the
the is considered for the level of the surface and is
similar to the level of the pressure at the
level especially over a low pressure area.

6. The temperature level is the same as the pressure at
pressure and temperature at different levels. This is
that the pressure level is the same as the pressure over the high
level and is considered for the level of the surface and is
that the temperature level is the same as the pressure at the

7. The temperature height curves for Royal Center, February 1931 show the temperature at the base of the inversion for the low pressure curve to be low and practically the same as that for the same relative position on the high pressure curve. This phenomenon is difficult to explain, however, the curves in general, demonstrate the existence of strong convection over a cyclone and a resultant cold tropopause temperature.

In connection with this idea, it is known that when polar continental air leaves its source region and crosses an open ocean surface, violent convection ensues. It is probable that, initially, when air temperatures are very low, this convection extends to about 8 or 9 kilometers. When this polar maritime air passes over land the convection phenomenon is diminished and the tendency towards the restoration of radiation equilibrium is strengthened. If in this case, we had a very strong flow of polar pacific air it is probable that the results indicated by the temperature-height curve represents that state where the convection process is still felt giving the extremely low tropopause temperature and a tropopause height slightly higher than normal conditions would warrant.

Reference to the daily sounding-balloon ascents made at Royal Center during the month shows several cases where there exists extremely steep lapse rates below the

7. The temperature change caused by light rays,

however, is not the temperature at the time of the

incident for the temperature curve is the law and

temperature is not the same for the same relative heat-

ness in the same pressure water. This temperature is

difficult to explain, however, the curve is normal,

because the relation of stress and strain is not a

linear one and a resulting cold temperature is observed.

On examination of this case, it is found that

the total mechanical energy is the same as the

energy of the other system, which is the same as the

is in the same case, initially, when the temperature

is very low, this condition is found to be the

condition. The total mechanical energy is the same as

the total mechanical energy is the same as the

energy of the other system, which is the same as the

is the same. It is the same, as the other system

the total mechanical energy is the same as the

indicated by the temperature of the system, which is

the same as the temperature of the other system

the total mechanical energy is the same as the

the total mechanical energy is the same as the

the total mechanical energy is the same as the

the total mechanical energy is the same as the

the total mechanical energy is the same as the

level of the tropopause and in the vicinity thereof, with marked inversions present just above the tropopause. A thorough and comprehensive study of this problem necessitates the investigation of the predominant wind direction. For the soundings cited, this essential data was missing in the majority of cases.

BIBLIOGRAPHY

1. W.R.Hines, F.R.S. - The Free Atmosphere in the Regions of the British Isles - Geophysical Memoirs #2.
2. David Brunt, 1934 - Physical and Dynamical Meteorology, Cambridge University Press, Cambridge, Mass.
3. Leroy T. Samuels - Sounding-Balloon Observations at Royal Center, Ind. During the International Month September 1930. Monthly Weather Review, Volume #59, November 1931, pages 417-426.
4. Leroy T. Samuels - Sounding-Balloon Observations made at Royal Center, Ind. During the International Month, February 1931. Monthly Weather Review, Volume #60, January 1932, pages 12-22.
5. Leroy T. Samuels - Sounding-Balloon Observations made at Broken Arrow, Okla. During the International Month, December 1929. Monthly Weather Review, Volume #59, August 1931, pages 297-309.
6. T.R.Gregg - International Aerological Soundings at Royal Center, Ind. May 1926. Monthly Weather Review, Volume #55, pages 293-307.
7. Leroy T. Samuels - Sounding-Balloon Observations made at Groesbeck, Texas, During the International Month, October 1927. Monthly Weather Review, Volume #57, June 1929, pages 231-246.

CONTENTS

1. Introduction - The Role of the Editor in the Journal of the American Statistical Association, Vol. 100, No. 1, 1995, pp. 1-2.
2. Editorial Board - Editorial Board, Vol. 100, No. 1, 1995, pp. 3-4.
3. Editorial Board - Editorial Board, Vol. 100, No. 1, 1995, pp. 5-6.
4. Editorial Board - Editorial Board, Vol. 100, No. 1, 1995, pp. 7-8.
5. Editorial Board - Editorial Board, Vol. 100, No. 1, 1995, pp. 9-10.
6. Editorial Board - Editorial Board, Vol. 100, No. 1, 1995, pp. 11-12.
7. Editorial Board - Editorial Board, Vol. 100, No. 1, 1995, pp. 13-14.
8. Editorial Board - Editorial Board, Vol. 100, No. 1, 1995, pp. 15-16.
9. Editorial Board - Editorial Board, Vol. 100, No. 1, 1995, pp. 17-18.
10. Editorial Board - Editorial Board, Vol. 100, No. 1, 1995, pp. 19-20.

BIBLIOGRAPHY (Cont'd)

8. V.F.K. Ojerknes - Physikalische Hydrodynamik, mit anwedung auf die dynamische Meteorologie.
9. E. Palmén - Aerologische Untersuchungen der Atmosphärischen Störungen mit Besonderer Berücksichtigung der Stratosphärischen Vorgänge - Helsingfors Centraltryckeriet - 1933 -.
10. H. Wexler - Cooling in the Lower Atmosphere and the Structure of Polar Continental Air - Monthly Weather Review, April 1933 , pages 122-136.

- [illegible]

Thesis
D76

Drouilhet

32850

Investigation of pressure
and temperature changes at
the base of the strato-
sphere.

Thesis
D76

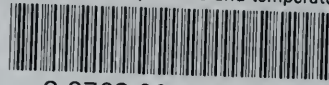
Drouilhet

32850

Investigation of pressure and
temperature changes at the base
of the stratosphere.

thesD76

Investigation of pressure and temperatur



3 2768 001 89504 8

DUDLEY KNOX LIBRARY